AD 600423

Shelter Research 1200 - Shelter Environmental Studies, Subtask 1213A - Humidity Control Study

SUMMARY [redacted]

OF

RESEARCH REPORT

MOISTURE IN SURVIVAL SHELTERS

APRIL 27, 1964

This is a summary of a report which has been reviewed in the Office of Civil Defense and approved for publication. Approval does not signify that the contents necessarily reflect the views and policies of the Office of Civil Defense.

CONTRACT NO. OCD-OS-62-51

Engineering and Industrial Experiment Station
University of Florida
Gainesville, Florida

Summary Prepared in
Engineering and Industrial Experiment Station
University of Florida
May, 1964

I. STATEMENT OF PROBLEMS

The Office of Civil Defense requested that the Department of Mechanical Engineering of the University of Florida, operating under the Florida Engineering and Industrial Experiment Station submit a proposal to investigate the general problems of moisture, humidity, and condensation in fallout shelters and to develop procedures and specifications for economical equipment to control these problems. A proposal was submitted and Contract No. OCD-OS-62-51, Subtask 1213A, between the Office of Civil Defense and the Florida Engineering and Industrial Experiment Station was awarded. The problem was broken down into four major approaches:

(1) A study of sources of moisture and condensate in occupied and unoccupied shelters including the effects of climate, ground water, permeability, ventilation, latent heat, dew point, and surface temperatures was made.

(2) An investigation of promising methods for reducing humidity, preventing leakage of moisture into shelters and controlling moisture and condensate was conducted.

(3) Commercial dehumidifying apparatus for use in survival shelters was evaluated.

(4) Chemicals which might be suitable for the absorption of moisture and the control of shelter humidity were investigated.

Comparative tests were performed on the basis of the information developed during the above evaluations. Conclusions were drawn and recommendations were made with respect to suitable apparatus and procedures necessary for control of humidity and moisture in survival shelters.

II. GENERAL PROCEDURE

Much of the investigation pursued the classical approach of literature survey,

theoretical investigation, laboratory or pilot-scale study, and full-scale application. There were occasions, however, when little or no information could be found to indicate previous work. Similarly, it was deemed expedient at times to proceed directly to a full-scale test, by-passing the construction and evaluation of laboratory scale apparatus.

At about the same time that the investigations were started, which are the subject of this report, the Contractor, was awarded another contract with the Office of Civil Defense. This Contract, No. OCD-OS-62-116, Subtask 1212A, was directed to the Simulated occupancy tests of survival shelters in many regions of the country. Since the procedures of the simulated occupancy tests often provided conditions that could be used to study the general subjects of humidity and moisture in shelters, it was possible in many cases to conduct full-scale investigations in actual operating (simulated) shelters, that might not otherwise have been warranted under the scope of the original contract. A much broader study of moisture and humidity was thus made possible.

III. MOISTURE SOURCES ASSOCIATED WITH SURVIVAL SHELTERS

An analysis was made of the various sources of moisture and modes of penetration into survival shelters. The investigation and study was concerned only with the effects that moisture and humidity would have on the environment of a survival shelter and did not attempt to evaluate their psychological or physiological effects. Listed below are the major sources of moisture in, and mechanisms of penetration into, survival shelters:

1. Water leakage into the shelter.
2. Vapor migration through the walls, floor, and ceiling.
3. Air infiltration into shelters on "standby" basis.
4. Moisture released by occupants due to the metabolism and attempts at

temperature control of the human body.

5. Moisture in vapor form contained in the air supplied to survival shelters for ventilation purposes.

Water Leakage in Shelter Areas. Leakage of water into shelters may be considered objectionable from three standpoints: (1) radioactive material could be carried into the shelter entrained or dissolved in the water that leaks into the shelter, (2) the damage associated with leakage could bring about psychological and physiological reactions among the occupants of the shelter, (3) the evaporation of moisture from the wetted surfaces of the leaking shelter could, under certain circumstances, add to the latent load in the ventilation air and adversely affect the shelter environment.

Under Contract No. OCD-OS-62-116, seventeen shelters in various geographic locations throughout the United States have been subjected to simulated occupancy tests; twelve of these shelters have a history of leakage. The leakage in these shelters was found to be related to cracks or ineffective waterproofing of the shelter, faulty plumbing, and flooding due to entryways being lower than the level of outside water sources. Table No. I lists the seventeen shelters by name, location, and type of leakage which occurred.

In the Napier Shelter which was tested in Gainesville, Florida, an attempt was made to correct the problem of leakage through the walls of the shelter and at the intersection of the walls and floor of the shelter by using various commercial products, all of which were advertised to stop leakage. None of these products were found to be effective although all were applied in strict conformance to the manufacturer's specifications and at least one of the manufacturer's representatives was present to observe the method of such application. It was concluded that to be effective, waterproofing needed to be accomplished at the time the shelter was under

TABLE I
OCCURRENCE OF WATER LEAKAGE
DURING SHELTER OCCUPANCY TESTS

Name and Location of Shelter	Type Construction	Did Leakage Occur?	Type Leakage
1. Broyles: Gainesville, Florida	A	Yes	1
2. Summerlin: Gainesville, Florida	B	Yes	2
3. Napier: Gainesville, Florida	A	Yes	3
4. Central Stores: Gainesville, Florida	C	No	
5. Houston Motor Compound: Houston, Texas	C	No	
6. Prototype Community: Reading, Pa.	D	No	
7. Hershey: St. Louis, Missouri	E	Yes	4
8. Control Center: St. Louis, Missouri	E	No	
9. Abo School: Artesia, New Mexico	E	No	
10. Francis: Tucson, Arizona	E	Yes	5
11. Airport Utility Tunnel: Tucson, Arizona	F	Yes	6
12. Robert's Dairy (Cow): Elkhorn, Nebraska	D	Yes	7
13. Irvingdale Shelter: Lincoln, Nebraska	D	Yes	8
14. P.S.D.C. Expedient: Ft. Belvoir, Virginia	G	Yes	9
15. P.S.D.C. 200-Occupant: Ft. Belvoir, Va.	C	Yes	10
16. P.S.D.C. 1000-Occupant: Ft. Belvoir, Va.	C	No	
17. N.N.M.C. 100-Occupant: Bethesda, Maryland	H	Yes	11

TYPE OF CONSTRUCTION

Type	Description
A	Semi-buired, concrete block
B	Buried, steel tank
C	Basement, reinforced concrete
D	Semi-buried, reinforced concrete
E	Buried, reinforced concrete
F	Buried, corrugated steel culvert
G	Above ground, earth filled walls
H	Buried, corrugated steel arch

Types of Leakage

1. Small leak in roof apparently due to crack in slab coupled with faulty water proofing.

2. Error in procedure in filling water supply tank, ruptured tank and shelter end wall.

3. Shelter leaked extensively. Roof membrane was inadequately lapped and may have torn due to shifting of earth cover. Hollow block walls partially filled up with water which then leaked into shelter at poorest mortar joints. Severe leakage at juncture of wall and floor slab.

TABLE I (Cont'd)

4. Due to a high water table, water rose into the shelter through a sump drain in the floor. By pumping 1 gallon per hour from the sump to keep the water level below floor level the floor was kept dry.

5. Above ground flood caused subsidence of poorly placed back fill, rupturing fill line to water tank. Water thus released below ground filled excavation and entered shelter around unsealed ventilation air inlet pipes.

6. Access manholes did not seal adequately and permitted entry of water during periods when water stood above tunnel after heavy rains.

7. Due to an overloading of earth on the shelter roof the supporting concrete cracked introducing a hole for the leakage of water. The excess of earth was removed, however, the hole remains and a patch should be made to prevent water leakage.

8. The elevation of the shelter entrance was below that of the area surrounding the shelter. Before an earth barrier was moved in front of the entrance, ground water from heavy rains ran into the shelter through the entrance. The earth barrier kept the shelter dry.

9. Water leaked through the layers of asphalt roofing paper buried 3 inches under the surface. Using a 4 mil continuous plastic membrane which replaced the roofing paper prevented leakage.

10. Toilet in basement overflowed due to stoppage or inadequate outfall to drain field. Actual cause not definitely ascertained.

11. Rainwater entered juncture of auxiliary access ramp and equipment room after draining along incomplete back filling.

construction and should be applied to the outside of the shelter walls.

The effect of water leakage, and resultant wetted surfaces, was evaluated, again using the Napier Shelter as an example. By taking advantage of a simulated occupancy test, being conducted under Contract No. OCD-OS-62-116, use could be made of air handling equipment which ventilated the shelter with air which was conditioned to duplicate severe summer conditions. The floor of the shelter was completely wetted and the constant C in the mass transfer equation:

$$\frac{dM}{d\theta} = CA \ (P_s - P_a)$$

Where: $dM/d\theta$ = rate of evaporation of water, lb/hour

C = constant, typical of particular shelter

A = wetted area, ft^2

P_s = saturation vapor pressure of water film on floor at floor temperature, lb/in^2

P_a = partial pressure of water vapor in ventilation air, lb/in^2

Once evaluated, the equation was reapplied to three periods of time when the shelter was actually under simulated occupancy conditions whereby it was determined that the effect of a completely wetted floor was equivalent to an increase in moisture loading of from four to seven percent.

The question of the significance of this moisture increase was considered and it was determined that a wet floor was advantageous, of no significance, or disadvantageous as the source of the heat flow to the floor was varied. When moisture was evaporated from a wetted surface within a shelter, as a result of heat transfer from within the shelter, the effective temperature of the shelter was decreased and the shelter made more habitable. On the other hand, if heat flowed into the shelter, through the floor for instance, and thereby caused evaporation from a

wet surface, the total enthalpy of the shelter was increased, causing an increase in effective temperature and a concomitant deterioration in shelter habitability. Finally, if the air adjacent to the wet floor had the same dew point as the water layer, no evaporation took place and the water film had no effect. It must be again emphasized that these conclusions were reached with no weight being given to other possible psychological or physiological effects of wet floors or dripping walls or ceilings.

Vapor Migration. Two shelters were equipped with dehumidifying apparatus and the steady-state moisture migration determined after equilibrium conditions of relative humidity had been reached. In the Broyles 12 person shelter, a structure with concrete block walls (all cells filled with concrete) and poured concrete walls and roof, vapor migration was substantial. The steady-state value reached was 3.7 liters of water per day when a one-horsepower dehumidifier was employed. The heat of condensation of this quantity of water plus the electrical input to the machine caused a continuous liberation of heat equivalent to a loading of nine persons. As a result, the shelter environment was greatly prejudiced, having reached an effective temperature of more than 83 F when the dehumidification experiment was discontinued.

The second shelter subjected to a dehumidification test was the Summerlin Shelter, a steel tank structure with a designed capacity of eighteen persons. Water removal leveled off at 0.2 to 0.3 liters per day which was suspected to represent "breathing" of the shelter with minor atmospheric pressure changes, rather than true vapor migration.

Air Infiltration. The problem of air infiltration, while probably of little or no significance during actual shelter operation, does become important during "standby" status. If infiltration continues, the shelter will become damp, since shelter wall temperatures are usually at or near the dew point temperature of humid summer air. As pointed out in the preceeding section, continuous operation of a

dehumidifier is not desirable because of the heat thus liberated.

Two shelters were subjected to infiltration tests in which they were first heavily dosed with carbon dioxide gas, then the declining concentration of gas with time was measured to evaluate air changes. The Broyles Shelter was found to experience 0.2 air changes per hour, while the Summerlin Shelter had only 0.008 changes per hour. The rate for the Broyles Shelter is high enough that steps should be taken to reduce it, prior to any attempt to maintain low interior relative humidity conditions.

IV. INTEGRAL DEHUMIDIFICATION METHODS AND DEVICES

Thermodynamics of Dehumidification. If a device to remove moisture from air is totally contained within the space in which it is to operate, it may be analyzed by the so called "black box" technique of thermodynamics. In this method of analysis, the details of construction and operation of the device in question are ignored and only the overall effects and energy flows are considered. Using this technique and referring to Figure 13 (abstracted from Final Report), consider the static or non-flow system illustrated there.

The "black box" is shown and is assumed to contain some type of a dehumidifying device (refrigeration engine, desiccant material, absorbent, or other means or moisture removal). Probably the only restriction that need be put on the box and its contents is that it not have within itself the ability to store energy. The "system", which is the shelter enclosure, is shown in an initial and a final state.

Now it is assumed that a process has been permitted to act within the "black box" for whatever time is necessary to bring about a reduction of the relative humidity within the "system" to some predetermined desirable value. This might be a reduction from 70% RH to 50% RH. Applying the first law of thermodynamics, which is

THERMODYNAMICS OF INTEGRAL DEHUMIDIFICATION DEVICES

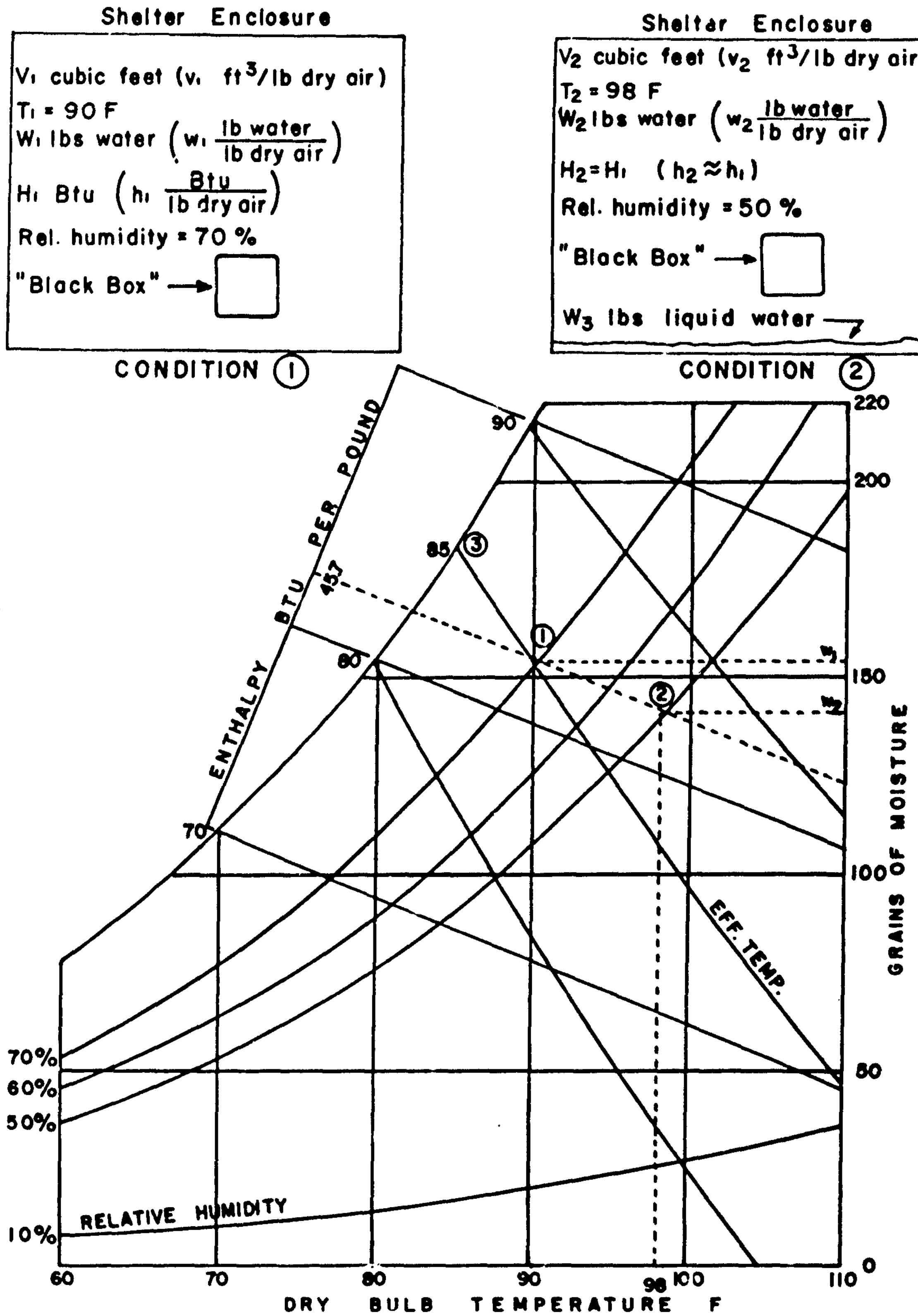


FIG. NO. 13

the statement of the conservation of mass-energy, to the system, it can be concluded that no energy enters or leaves so that the process can be considered one of constant enthalpy and can be so indicated on the chart in Figure 13. Since conditions in the shelter go from a higher specific humidity to a lower one along a constant enthalpy line, the final condition must lie downward and to the right and on the enthalpy line through Point 1 as shown. Further study of Figure 13 shows that the effective temperature lines and the enthalpy lines are not parallel and that movement along the enthalpy line downward and to the right would bring about a higher effective temperature even though the final condition would be at a lower relative and specific humidity. Thus, the increase in dry bulb temperature caused by condensing moisture in the air would bring about an increase in the effective temperature even though the relative humidity in the space were reduced. A dotted line on Figure 13 shows the path of this process from Condition 1 to Condition 2. Thus, it may be concluded that irrespective of the methods used to bring about dehumidification whether chemical or mechanical, the net effect of such dehumidification would be an increase in effective temperature unless the heat associated with dehumidification is rejected outside of the space to be conditioned.

The theory described previously when applied to mechanical dehumidifiers or to chemical absorption dehumidification, shows that neither method can be used for control of environmental conditions in occupied survival shelters. However, either method could be employed as a means of keeping shelters dry and afford a protection to canned goods, bedding, communication equipment, and other necessary shelter furnishings during periods of standby conditions.

CONTROL METHODS AND DEVICES WITH EXTERNAL HEAT SINKS

Excess Ventilation Air. If it may be assumed that the ambient air surrounding the shelter has the capacity to absorb moisture and heat, the simplest method of

environmental control consists of a fan which would pump ambient air through the shelter in quantities sufficient to absorb the sensible and latent heat produced by the occupants and equipment within the shelter. It can be seen that the effectiveness of this method would vary from one geographic location to another and be dependent on the climatic conditions that existed during the time the shelter was occupied and since there is no means of predicting when an atomic attack might occur, the necessary air flows for controlling shelter environment would need to be based upon the typical extremes that might reasonably be expected in the climatic conditions for a particular location. Thus, environmental control would be more difficult in hot, humid climates than in cooler climates.

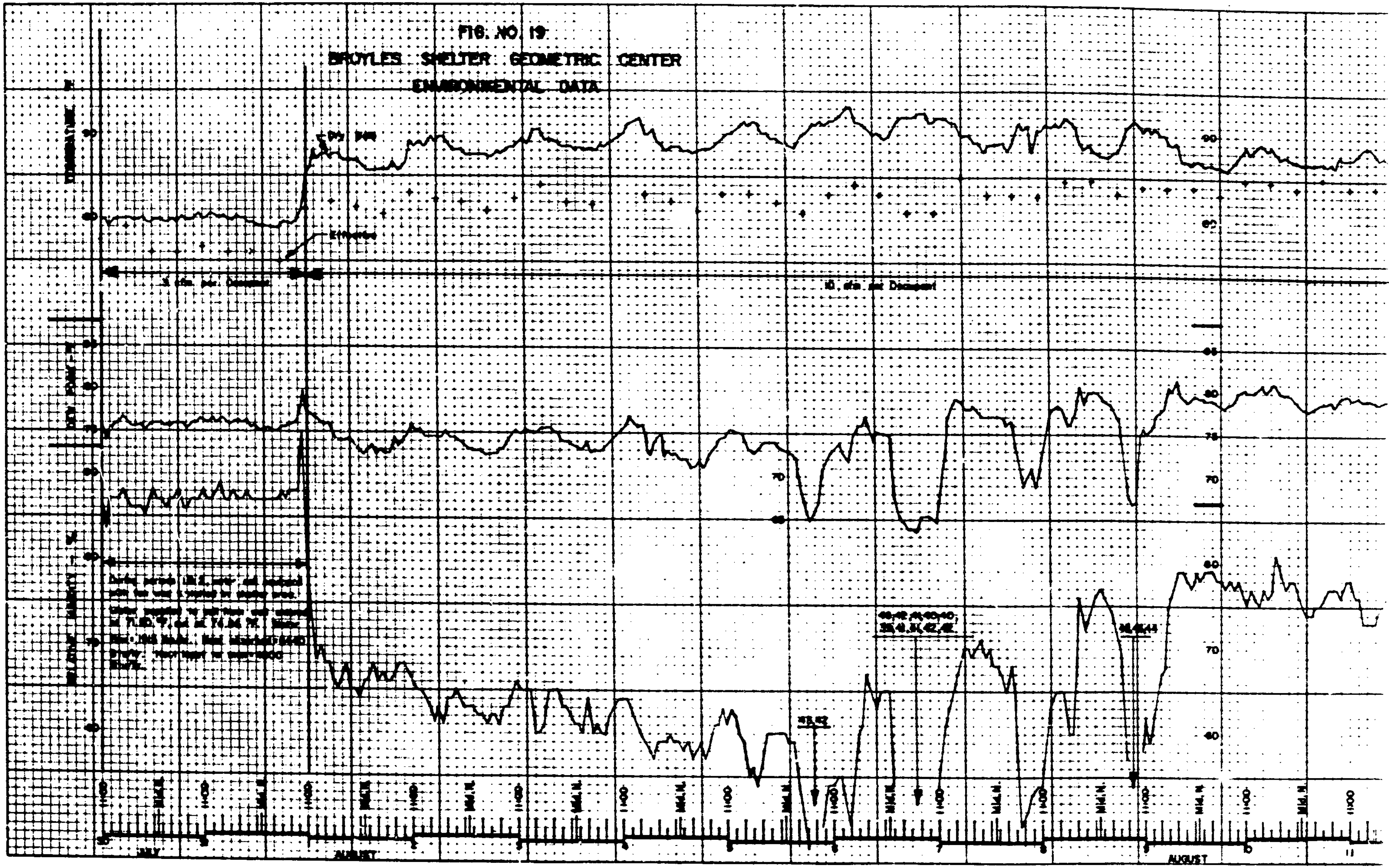
In the case of underground shelters, ambient conditions affect ground temperatures, high ambient temperatures bring about an increase in the soil temperatures which reduce the capability of the earth surrounding the shelter to absorb heat produced within the shelter. Fortunately, a lag exists between the peaks in temperature for ambient air and soil which aids in shelter environmental control. In general, it may be stated that ambient air and soil conditions are such that control can be achieved by means of excess ventilation air for at least ten months out of the year, in practically all geographic locations. Figure 19 shows a history of environmental conditions in a twelve occupant partially buried survival shelter during a two week period of simulated occupancy and illustrates the changes that occur in such a shelter when various air flows are used for ventilation purposes. Since the metabolic process of human beings requires oxygen and produces CO_2, there are certain minimum requirements with respect to ventilation air. Previous investigation has established 3 cubic feet of ventilation air per occupant as an adequate quantity of ventilation air to supply oxygen and control CO_2 concentration. In some cases this quantity of air may be sufficient to remove heat and moisture

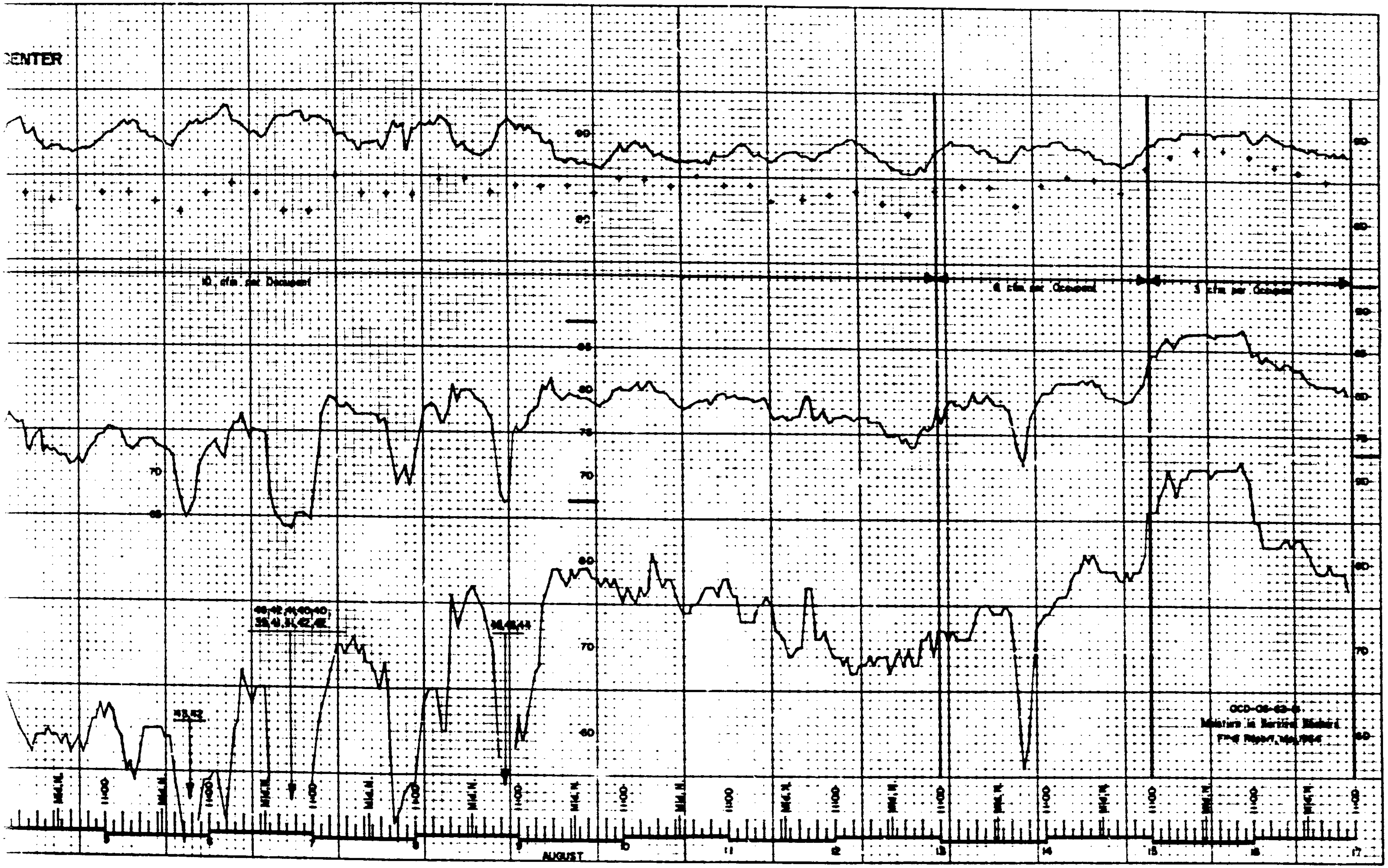
produced by the metabolic process, but in many cases where climatic conditions are severe, there will be periods during the summer months where 3 cubic feet of air per person will not be adequate for heat and moisture control. Investigations are presently underway to determine the quantities of air necessary to maintain environmental conditions below 85 F effective temperature (this effective temperature being considered the maximum that could be tolerated by human beings over long periods of time) in survival shelters for various geographic locations throughout the United States.

Use of Ground Water for Absorbing Sensible and Latent Heat. Where ground water is obtainable from shallow wells at temperatures of 72 F or less such water can be used to absorb sensible and latent heat by passing this water through a coil located in the shelter space and circulating the shelter air across such a coil. Figure 19 illustrates that it is possible to maintain an occupied shelter in the comfort zone even though the shelter is located in a hot, humid climate. Since, in general, ground water temperatures are less than the peak summer ambient temperatures that may be expected in practically all geographic locations of the United States, the use of ground water as a means of environmental control in survival shelters offers much promise, provided that an excessive expenditure of energy for pumping is not necessary.

Air Conditioning Systems. Commercial air conditioning systems are available and could be adapted for installation in shelters without the need for research or developmental programs. In the case of underground shelters in most localities soil temperatures would be such that external heat loads on the shelter walls would either be nonexistent or insignificant and the system would need to absorb only the heat produced within the shelter. Since the metabolic heat production of individuals has been well established by previous investigations at approximately 400 Btu per

FIG. NO. 19
BROYLES SHELTER GEOMETRIC CENTER
ENVIRONMENTAL DATA





CENTER
10 cfm per Occupant
6 cfm per Occupant
3 cfm per Occupant
AUGUST
OCD-OS-62-?
Moisture in Survival Shelters
Final Report, May 1964

(12) b

hour per sedentary adult, it can be seen that a ton of refrigeration (12,000 Btu per hour of heat removal) could absorb the heat released by 20 occupants of a survival shelter and leave a suitable safety factor to take care of heat produced by cooking, lighting, mechanical devices, and additional activity which would increase the metabolic heat load of certain occupants. A one-ton air conditioner may be assumed to require one kilowatt hour of electrical energy for one hour of operation.

VI. POWER REQUIREMENTS FOR ENVIRONMENTAL CONTROL

Power Sources. Since any device that would be useful as a means of environmental control would require power, it was deemed advisable to investigate the power sources that would be available under conditions that would exist following an all-out atomic attack. It is not likely that the public utility systems could withstand such an attack and maintain their generating and distributing capacity without repair and maintenance for a period that might extend through fourteen days. Therefore, a source of power other than the existing utilities must be considered. One such source is the muscular power of the occupants of a survival shelter. Previous investigators have studied the ability of human beings to produce energy by muscular activity and a review of their findings indicates that the average man might be expected to produce one-tenth of a horsepower for a period not to exceed two hours and that this average man would then need a period of rest of approximately four hours before he could be called upon for further muscular activity. A study of the power requirements for a ventilation system or for a ground water cooling system for use in shelter environmental control indicates that by proper scheduling, a group of individuals could supply sufficient power, for the operation of fans or pumps and thus, maintain the environment of a shelter below an effective temperature of 85 F which is considered a maximum tolerable limit for long term occupancy. While it is possible to use the muscular effort of

the occupants of a survival shelter as means of environmental control little margin of safety is available in such a method and even minor health problems could make this method ineffective. For this reason, it is recommended that each shelter should be equipped with its own power source.

A study of power sources included storage batteries, solar cells, wind power, internal combustion engines, and similar engines coupled to electric generators. Results of this study indicated that from a standpoint of flexibility, safety, and dependability that an air-cooled diesel engine driving an electric generator would probably be the best all-around solution to the auxiliary power problem. The major drawback to such a system would be a relatively high first cost. However, this factor would change if a mass market were developed for such an item.

VIII. CONCLUSIONS

1. It was concluded that metabolic moisture and heat produced by the occupants of the shelter was the major source of heat and moisture in underground survival shelters. Leakage, infiltration, and moisture migration can be considered as minor sources of moisture by comparison.

2. The effect of moisture in ventilation air can be overcome by increasing the rate of ventilation air provided that the ventilation air has some ability to absorb moisture.

3. Integral dehumidifying devices either chemical or mechanical are not satisfactory unless the power input to the device and the latent heat of vaporization that is released when moisture in the air is condensed is transferred from the boundries of the shelter.

4. Environment within a shelter can be controlled by: (a) excess ventilation air, (b) ground water, (c) air conditioning systems. In most localities the tem-

perature of the earth is such that the earth forms a heat sink and aids the three methods of control previously outlined.

5. The source of power most readily available in survival shelters is the muscular abilities of the occupants of such a shelter. An investigation indicates that this power would be adequate for the operation of fans or pumps that would be able to control shelter environment.

6. A dependable auxiliary power system would consist of an air-cooled diesel engine coupled to an electric generator.

7. The most satisfactory auxiliary power system would consist of a diesel-powered generator backed up with manually operated ventilation devices which could be operated by the leg muscles of the shelter occupants.

8. It was concluded that it would not be wise to depend on electrical supply from the public utilities as a sole source of power for a shelter.

9. Steps needed to assure a dry shelter had to be taken at the time the shelter was under construction and the waterproofing should be applied to the outside of the shelter walls. Very little could be done to reduce leakage into the shelters by the application of materials to the interior of the shelter structure.